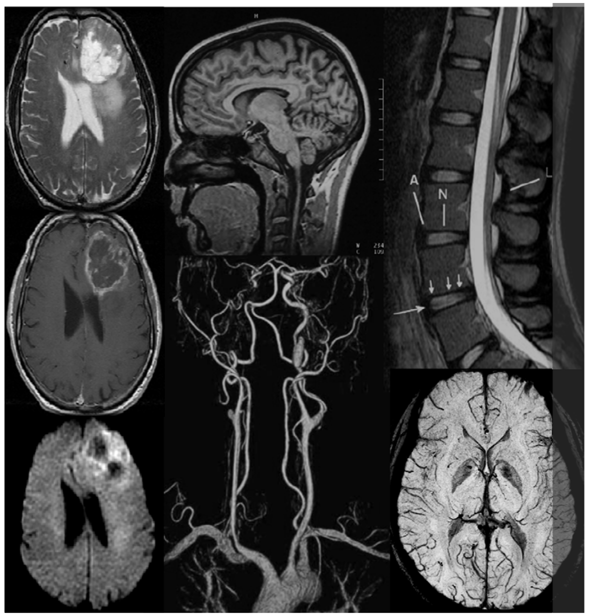


磁振影像學MRI
課程介紹與基本原理

盧家鋒 教授

國立陽明交通大學
生物醫學影像暨放射科學系
alvin4016@nycu.edu.tw

上課教材與課程影片

- 提供課後複習或其他未修課同學自修
- https://cflu.lab.nycu.edu.tw 點選Contents → Teaching Materials → MRI (UG)

上課方式

- 內容講解
- 相關國考題

95～113年： 放射線器材學
放射線診斷原理與技術學
https://cflu.lab.nycu.edu.tw/CFLu_course_BIRSmri.html

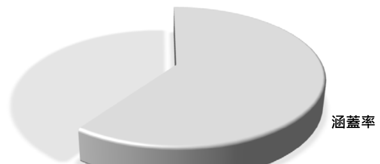
(B) 3.下列關於逆磁性（diamagnetism）物質的敘述，何者正確？
A.逆磁性物質的磁化率（susceptibility）為正值
B.含氧血紅素（oxyhemoglobin）為逆磁性物質
C.在沒有外加磁場的情況下，逆磁性物質有一淨磁矩（net magnetic moment）
D.磁振造影對比劑 Gd 螯合物為逆磁性物質
(103 年第二次放射線器材學第 39 題)

(D) 4.若磁振造影儀使用永久磁鐵，主磁場（B0）方向和激發射頻磁場（B1）方向通常與地面關係為何？
A.平行；平行
B.垂直；垂直
C.平行；垂直
D.垂直；平行
(103 年第一次放射線器材學第 36 題)

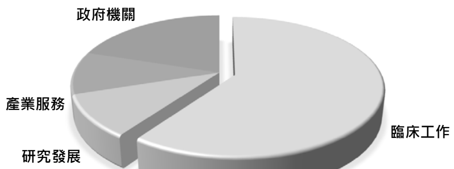
磁振影像學Magnetic Resonance Imaging
http://cflu.lab.nycu.edu.tw/CFLu_course_BIRSmri.html

- **磁振成像原理**
  - 硬體設備、射頻脈衝、組織對比、影像重建、脈衝波序、影像假影與安全...等

放射師執照 (MRI)



發展潛能



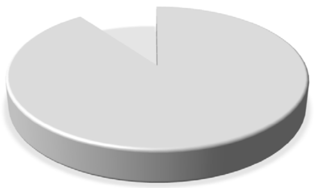
EMI course

醫用磁振學Magnetic Resonance in Medicine

http://cflu.lab.nycu.edu.tw/CFLu_course_BIRSmrm.html

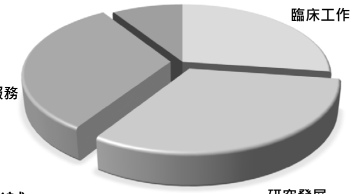
- 磁振造影技術
  - 對比劑增強、功能性影像、擴散影像、血管攝影、頻譜分析、平行造影...等
- 陽明磁振造影室參觀與掃描
  - 磁振造影室環境介紹、操作介面、影像掃描

放射師執照 (MRI)



別擔心考試...

發展潛能



Magnetic Resonance Imaging

	Topics
Class 1	Introduction; Basic principles of MRI & Instrument
Class 2	Radio Frequency Pulse
Class 3	Relaxation time: T1, T2, and T2*
Class 4	TR, TE, and tissue contrast
Class 5 (9/29)	Off
Class 6 (10/6)	Off
Class 7	Image construction: slice selection & spatial encoding
Class 8	Image formation: K space
Class 9 (10/27)	**Midterm exam**

Magnetic Resonance Imaging

	Topics
Class 10	Pulse sequences I: spin echo (SE)
Class 11	Pulse sequences II: gradient echo (GRE)
Class 12	Pulse sequences III: echo planar imaging (EPI)
Class 13	Tissue suppression techniques
Class 14	Artifacts in MRI
Class 15	Safety issues in MRI
Class 16 (12/15)	**Final exam**

參考書籍

- MRI The Basics (4th edition)
  - Ray H. Hashemi, William G. Bradley, Christopher J. Lisanti
  - Lippincott Williams & Wilkins,2017
- MRI in Practice, (5th edition)
  - Catherine Westbrook, Carolyn Kaut Roth, John Talbot
  - Wiley Blackwell, 2018

評分標準

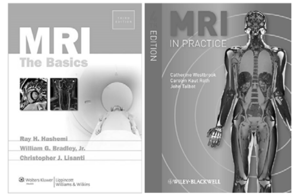
- 出席率&課程參與度 (20%)
- 期中考 (40%)：選擇與簡答題
- 期末考 (40%)：選擇與簡答題

包含國考精選題 !!

本週課程內容 http://cflu.lab.nycu.edu

- **磁振造影設備**
- **磁振原理**

- **MRI The Basics (3rd edition)**
  - Chapter 2: Basic Principles of MRI
- **MRI in Practice, (4th edition)**
  - Chapter 1: Basic Principles
  - Chapter 9: Instrumentation and equipment

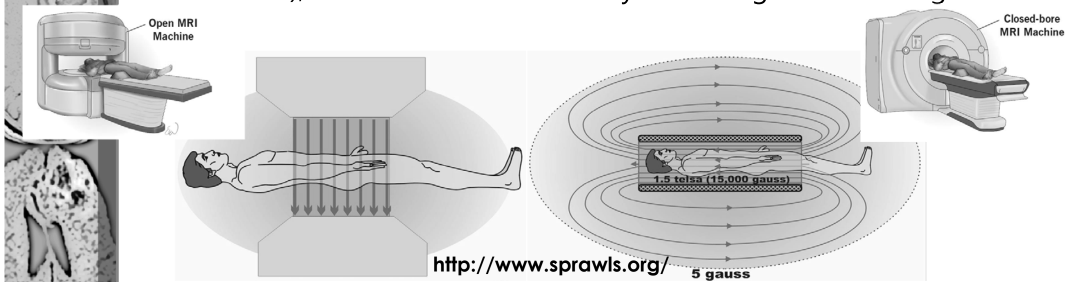


磁振造影設備

MRI Instrument

External B_0 Magnetic Field

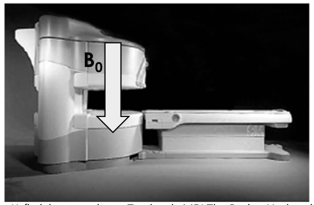
- On the order of 1 Tesla (1T) = 10000 Gauss (0.5 Gauss for earth's magnetic field in average)
- Required magnetic uniformity is less than 5 ppm (parts per million), which can be achieved by shimming and shielding.

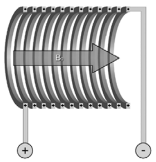


Types of Magnets

alnico alloy: 鋁aluminum(Al)、鎳nickel(Ni)、鈷cobalt(Co)合金

- Permanent magnets (for open MRI scanners), always stay on
- Resistive magnets (for low field MRI), can be turned on/off
- Superconducting magnets (the most common today)
  - operate near absolute zero temperature
  - generate a high B_0 without generating significant heat
  - require cryogens (interior 4°K liquid helium; outer 77°K liquid nitrogen), very expensive !!
  - Niobium-titanium alloy (鈮鈦合金)



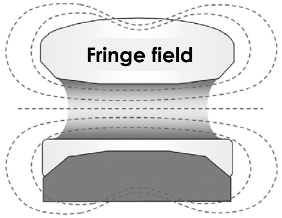


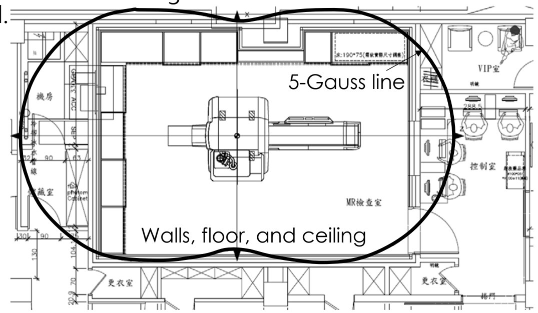
(屏蔽)

Shielding

1) Prevent extraneous electromagnetic waves from contaminating/distorting the MR signal
2) Reduce electromagnetic field generated by the MR scanner

- **Passive (magnetic) shielding**: scanner room with galvanized steel plates
  - RF shielding is accomplished by lining the scan room walls with copper.
- **Active shielding**: additional solenoid electromagnets located around the outside of the main magnet coil.
- **5 Gauss line** – safety zone





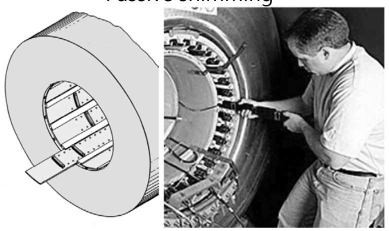
(補墊)

Shimming

Generally **passive shimming** is used to get the magnetic field to a particular level of homogeneity and then **active shimming** is used to optimize for each patient examination.

- Passive shimming
  - involving the use of ferromagnetic materials, typically iron or steel, placed in a regular pattern at specific locations along the inner bore of the magnet.
- Active shimming
  - performed by an electro-magnetic coil and can be used to shim the system for each patient or even each sequence within a protocol.

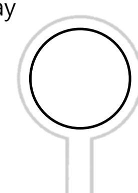
Passive shimming



12-24 sliding trays arranged symmetrically with metallic shims
http://mriquestions.com/passive-shimming.html

Coils

- Gradient coils
  - Shim coil – increase B_0 homogeneities
  - Imaging gradient coil – intentional perturbation for spatial encoding
- Transmit and/or receive RF coils
  - Linear phase or quadrature (receive or transmit)
  - Surface or volume (Helmholtz or solenoid)
  - Single or phased-array

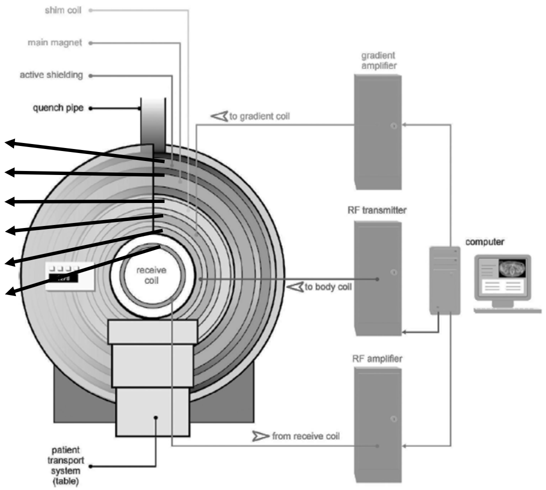


Solenoid coil

Helmholtz coil

Setup

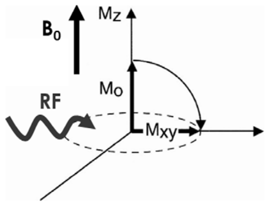
- Outer → inner
  - Active shielding
  - Main magnet
  - Shim coil
  - Gradient coil
  - Body coil
  - Receive coil



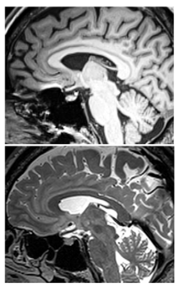
磁振原理

MR Principles

Procedure of MRI

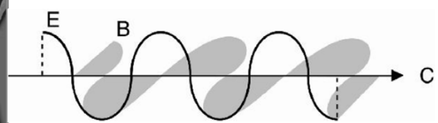


- 1. Alignment (magnetization) B_0
- 2. Precession $\omega_0 = \gamma B_0$
- 3. Resonance (given B_1 by RF with ω_2) $\omega_1 = \gamma B_1$, $B_1 \perp B_0$
  - The most effective resonance is produced when $\omega_0 = \omega_2$
- 4. MR signal (EMF, electromotive force)
- 5. Imaging (Pulse sequencing)
  - Image Contrast: Relaxation time
  - Spatial localization: Spatial Encoding



Electromagnetic Waves

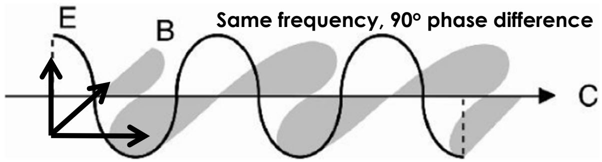
- All travel at the speed of light $c = 3 \times 10^8$ m/sec
- Maxwell's wave theory:
  - an electric field *E*
  - A magnetic field *B*



	Frequency (Hz)	Energy (eV)	Wavelength (m)
Gamma rays and X-rays	10^{24}	10^{10}	10^{-16}
	10^{23}	10^{9}	10^{-15}
	10^{22}	10^{8}	10^{-14}
	10^{21}	10^{7}	10^{-13}
	10^{20}	10^{6} (1 MeV)	10^{-12} (1 pm)
	10^{19}	10^{5}	10^{-11}
	10^{18}	10^{4}	10^{-10}
Ultraviolet	10^{17}	10^{3} (1 keV)	10^{-9} (1 nm)
	10^{16}	10^{2}	10^{-8}
Visible light	10^{15}	10^{1}	10^{-7}
Infrared	10^{14}	10^{0} (1 eV)	10^{-6} (1 μ)
	10^{13}	10^{-1}	10^{-5}
Microwaves	10^{12} (1 GHz)	10^{-2}	10^{-4}
	10^{11}	10^{-3}	10^{-3} (1 mm)
	10^{10}	10^{-4}	10^{-2} (1 cm)
	10^{9}	10^{-5}	10^{-1}
MRI	10^{8} (100 MHz)	10^{-6}	10^{0} (1 m)
	10^{7}	10^{-7}	10^{1}

Electromagnetic Waves

- The angular frequency **$\omega = 2\pi f$**, f is linear frequency
- We are interested in the magnetic field rather than the electric field
  - Electric field generates heat



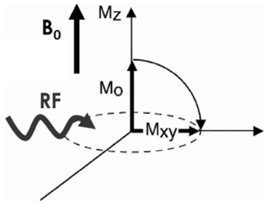
Changes in the E generates the B, and vice versa.

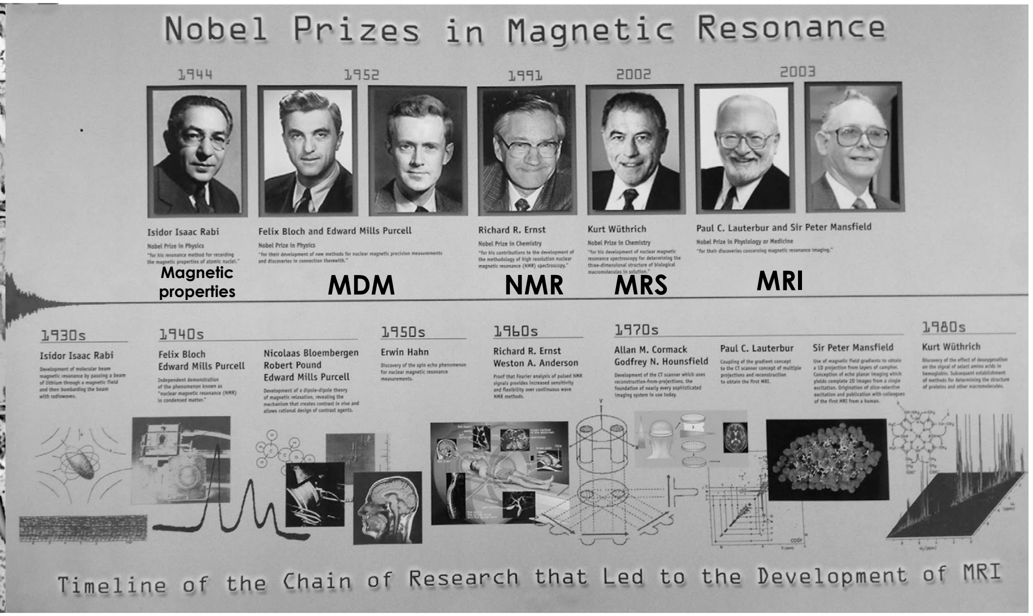
Radio frequency (RF) pulse

- The electromagnetic pulse used in MRI to get a signal is called an RF pulse.

	Frequency (Hz = Hertz)	Energy (eV = electron volts)	Wave Length (m = meters)
X-ray	1.7-3.6 × 10^{18} Hz	30-150 KeV	80-400 pm
Visible light (violet)	7.5 × 10^{14} Hz	3.1 eV	400 nm
Visible light (red)	4.3 × 10^{14} Hz	1.8 eV	700 nm
MRI	3-100 MHz	20-200 meV	6-60 m

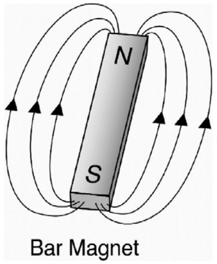
AM radio frequency	0.54-1.6 MHz (540-1600 kHz)
TV (Channel 2)	Slightly over 64 MHz
FM radio frequency	88.8-108.8 MHz
RF used in MRI	3-100 MHz

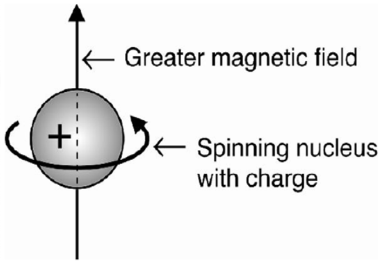




Spins and electromagnetic field

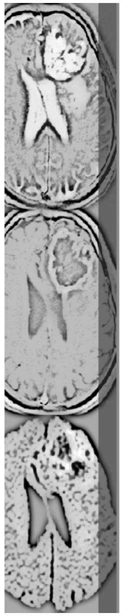
- **Felix Bloch** (Standard University, Nobel prize in physics, 1952)
  - Any spinning charged particle (such as the **hydrogen nucleus**) creates an electromagnetic field.





Magnetic dipole moment (MDM)

1905.10.23~1983.09.10

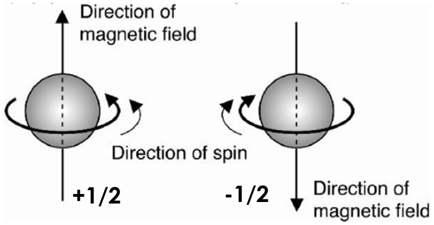


Quantum theory: Energy levels

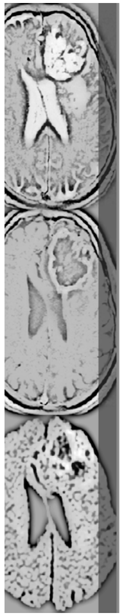
- The hydrogen nucleus (a proton) has a **spin quantum number (S)**

  S (^{1}H)=1/2
- The number of energy states of a nucleus

  # of energy states = 2S+1 (for ^{1}H = 2)

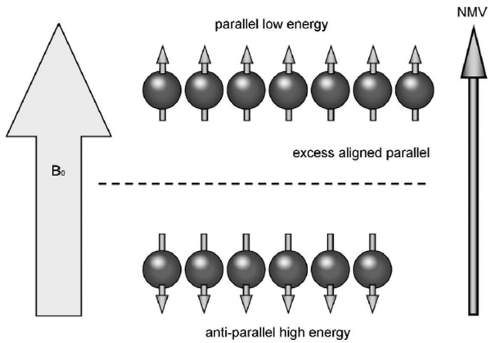


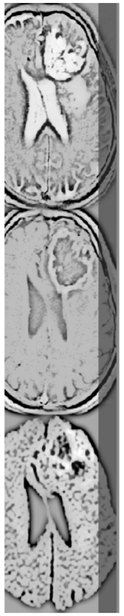
S (^{23}Na)=3/2
# of energy states = 2 (3/2) +1
= 4
(-3/2, -1/2, 1/2, 3/2)



Net Magnetic Vector (NMV)

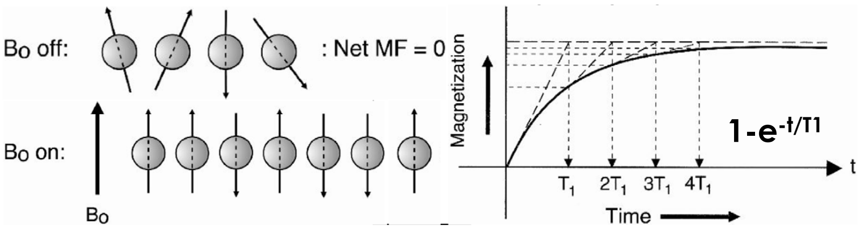
- With B_0, protons line up and approximately half spin-up (parallel, low energy) and half spin-down (anti-parallel, high energy).
- About one in a million more protons point in the direction of B_0.
- ppm (parts per million)

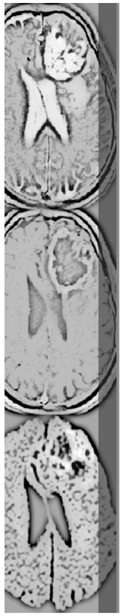




Alignment & T1 Relaxation time

- At time t = 0, proton spins are distributed randomly and net magnetic field is zero.
- Immediately after B_0 is presented, magnetization increases over time.

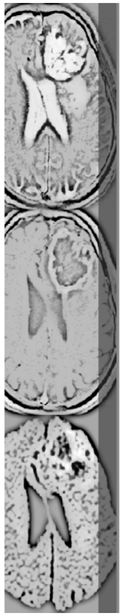




Spin and Precession

- Wheel rolling: spin
- Gravity: B_0
- Spiral precession

Magritek videos on youtube (6:33)!!



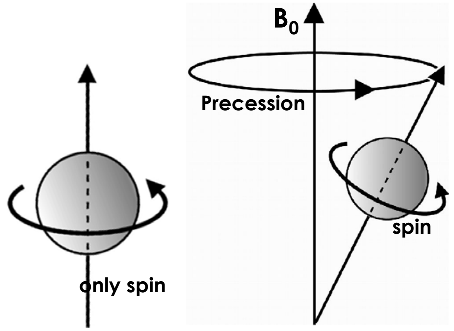
Precession

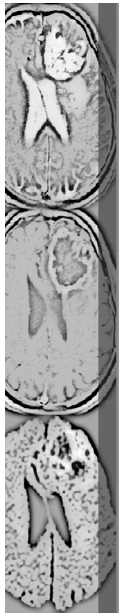
- With B_0, the proton not only spins about its own axis, but also precesses about the axis of the B_0.
- Each proton spins much faster about its own axis than it rotates around the axis of the B_0.
- **Larmor equation (frequency)**

  $\omega = \gamma B_0$

  γ is gyromagnetic ratio (MHz/T)

For B_0 from 1.5T → 3T
ω = 42.6 x 1.5T = 63.9 MHz
= 42.6 x 3.0T = 127.8 MHz
The RF range for MRI !!



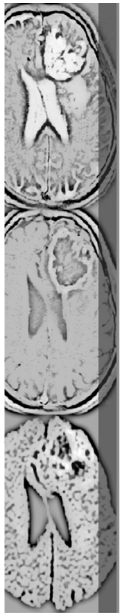


Magnetic dipole moment (MDM)

- An MDM is found in any nucleus with **an odd number of protons, neutrons, or both**.
- MDM is the signal source of MRI.

		Spin Quantum Number (S)	Gyromagnetic Ratio (MHz/T)
1P0N	^1H	1/2	42.6
9P10N	^{19}F	1/2	40.0
11P12N	^{23}Na	3/2	11.3
6P7N	^{13}C	1/2	10.7
8P9N	$^{17}0$	5/2	5.8

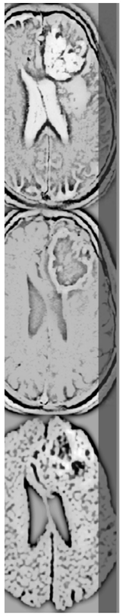
S ≠ 0, can be MR signal source



Hydrogen Nucleus (^1H)

- We use hydrogen for imaging because of…
  - its abundance (about 60~70% of body is water)
  - Hydrogen protons (^1H) in water (H_2O) and fat ($-CH_2-$)
  - its high MR sensitivity (high gyromagnetic ratio, γ = 42.58 MHz/T)

		Spin Quantum Number (S)	Gyromagnetic Ratio (MHz/T)
1P0N	^1H	1/2	42.6
9P10N	^{19}F	1/2	40.0
11P12N	^{23}Na	3/2	11.3
6P7N	^{13}C	1/2	10.7
8P9N	$^{17}0$	5/2	5.8



Magnetic Susceptibility, χ

- χ is the measure of magnetizability of a substance.
- The χ is defined as the ratio of the induced magnetic field (M) to the applied magnetic field H:

  $M = \chi H$ or $\chi = M/H$.

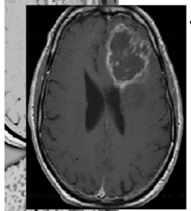
- The *magnetic induction field* or *magnetic flux density*, B, is the net magnetic field effect caused by an external magnetic field H:

  $B = \mu H = (1+\chi)H = H + M$.

  μ represents the *magnetic permeability*.

Magnetic Substances

- **Diamagnetic**
  - No unpaired orbital electrons
  - Under an external B_0, a weak M is induced in the opposite direction to B_0 ($\chi<0$ and $\mu<1$).
  - Most tissues in body are diamagnetic.



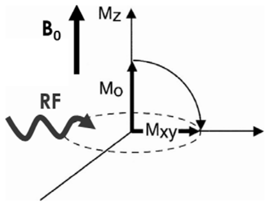
- **Paramagnetic**
  - Unpaired orbital electrons
  - M is in the same direction as B_0 ($\chi>0$ and $\mu>1$).
  - Become demagnetized once the B_0 has been turned off.
  - Dipole-dipole (proton-proton and proton-electron) interactions cause T1 shortening (bright signal on T1-weighted images)
  - gadolinium (Gd) chelates – contrast agent
- **Superparamagnetic**
  - breakdown products of hemoglobin: deoxyhemoglobin, methemoglobin, hemosiderin

Magnetic Substances

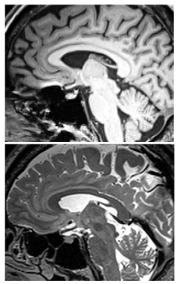
- **Ferromagnetic**
  - Become permanently magnetized even after the magnetic field has been turned off ($\chi>>0$ and $\mu>>1$).
  - Iron (Fe), cobalt (Co), and nickel (Ni)
  - Aneurysm clips and shrapnel

potential projectiles! Safety issue!

Procedure of MRI



- ☑ Alignment (magnetization) B_0
- ☑ Precession $\omega_0 = \gamma B_0$
- ☐ Resonance (given B_1 by RF with ω_2) $\omega_1 = \gamma B_1$, $B_1 \perp B_0$
  - The most effective resonance is produced when $\omega_0 = \omega_2$
- ☐ MR signal (EMF, electromotive force)
- ☐ Imaging (Pulse sequencing)
  - ☐ Image Contrast: Relaxation time
  - ☐ Spatial localization: Spatial Encoding



THE END

alvin4016@nycu.edu.tw